The Variable Outflow from the Chukchi Shelf to the Arctic Ocean

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LONG TERM GOALS

My long-term goal is to understand the mean and time-varying density structure and circulation dynamics of the Chukchi/Beaufort continental slope of the Arctic Ocean and how the slope interacts with the adjacent shelves and basin.

OBJECTIVES

The field effort and data analyses are addressing the following questions and objectives:

1. What are the characteristics of the shelf outflow from the Chukchi Sea to the Arctic Ocean?

2. What is the variability of these outflows and their water properties?

3. Which upstream processes are principally responsible for the variability?

4. contribute to the SBI goals by illuminating the mechanisms of shelf-basin exchange; and

5. promote further improvements in the rapidly growing array of models of arctic circulation, hydrographic structures, and variability by providing measurements against which to test the fidelity of these models.

The measurements include moored time series, supplemented by hydrographic and other ship-borne data. Our focus is both on the transformation and outflow from the shelf of Pacific waters that have entered through Bering Strait [*Weingartner et al.*, 2005; *Woodgate et al.*, 2005a; b; Pickart et al., 2005], and on providing a context in which the SBI process studies can be embedded.

APPROACH

Our effort is part of a broader, interdisciplinary effort being undertaken by the NSF-ONR Shelf-Basin Interactions (SBI) project as part of NSF's global change program, ARCSS (Arctic System Science). My specific program is a co-ordinated effort with Knut Aagaard and Rebecca Woodgate (both at the University of Washington). We deployed 4 oceanographic moorings on the Chukchi Shelf and slope

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[Barrow Canyon (ca. 80 m depth), the Central Channel (ca. 50 m), and on the north-central shelf downstream of Herald Valley (ca. 70 m and 110 m)]. The moorings were initially deployed from the USCG icebreaker Polar Star in September 2002, re-covered and re-deployed in September 2003, with the final recovery cruise conducted in September-October 2004. The shelf moorings are examining the flow and thermohaline properties of the shelf and the slope moorings will measure these characteristics near the shelfbreak of the northern Chukchi Sea and in the western Beaufort Sea. Each mooring includes ADCPs for measuring vertical profiles of currents and temperature-conductivity recorders for measuring temperature and salinity. The mooring deployment/recovery cruises also involve extensive CTD, bottle sampling, and vessel-mounted-ADCP transects over the Chukchi shelf and along transects that cross the Chukchi-Beaufort shelfbreak and slope. In closely related efforts, R. Pickart, WHOI maintained a mesoscale array on the Beaufort slope near 152°W, and J. Swift, SIO provided CTD/rosette sections to support the mooring work. These sections also included ADCP measurements that give detailed spatial information about the velocity field. To provide a context for the process studies and the overall SBI effort, we are also examining other data sets that uniquely contribute to understanding the modification of the Pacific inflow, to its role and fate in the Arctic Ocean, and to the larger role of arctic shelf-basin interaction in the global ocean.

WORK COMPLETED

Final data processing has been completed and all moored data are being prepared for submittal to JOSS/EOL for archiving, as designated by the SBI program.

In our analysis work we have made a considerable effort to synthesize a variety of data to provide a broad perspective on arctic shelf-basin. Our analysis efforts under this grant have resulted in five published papers, along with numerous presentations at national and international meetings. Several of the published results new this year are described below.

RESULTS

The effects of changes in the processing of freshwater in the Arctic and sub-Arctic are of global importance, and the SBI region is an integral part of this problem set. For example, the inflow of freshwater though Bering Strait is equivalent to about three-fourths of the total runoff into the Arctic Ocean [*Woodgate et al.*, 2006].

The annual cycle of freezing and melting of sea ice is of major importance to conditions on the arctic shelves, including the SBI region, and the ensuing shelf conditions also affect the adjacent basins. Much of the ice production has been thought to occur in coastal polynyas, where extremely saline waters may form [*Aagaard et al.*, 1985; *Weingartner et al*., 2005]. To explore this problem set, we have examined conditions in the St. Lawrence Island polynya on the northern Bering shelf (Figure 1), which feeds the Bering Strait throughflow and downstream Chukchi Sea. Using the records from fourteen year-long instrumented moorings deployed south of St. Lawrence Island, along with oceanographic drifters, we have assessed the circulation over the central Bering shelf and the role of polynyas in forming and disseminating saline waters over the shelf. We have paid particular attention to evaluating the *Gawarkiewicz and Chapman* [1995] model of eddy production within coastal polynyas. Principal results of our analysis include: 1) The northern central shelf near-surface waters exhibit westward flow carrying low-salinity waters from the Alaskan coast in fall and early winter, with consequences for water mass formation and biological production. 2) Within the St. Lawrence polynya, the freshening effect of winter advection is about half as large as the salting effect of surface

brine flux resulting from freezing. 3) Brine production over the Bering shelf occurs primarily offshore, rather than within the polynyas. 4) We find little evidence for the geostrophic flow adjustment predicted by recent polynya models. 5) In contrast to the theoretical prediction that dense water from the polynya is carried offshore by eddies, we find negligible cross-shelf eddy density fluxes within and surrounding the polynya and very low levels of eddy energy that decrease from fall to winter, even though dense water accumulated within the polynya and large cross-shore density gradients develop. 6) It is possible that dense polynya water was advected downstream of our array before appreciable eddy fluxes materialized.

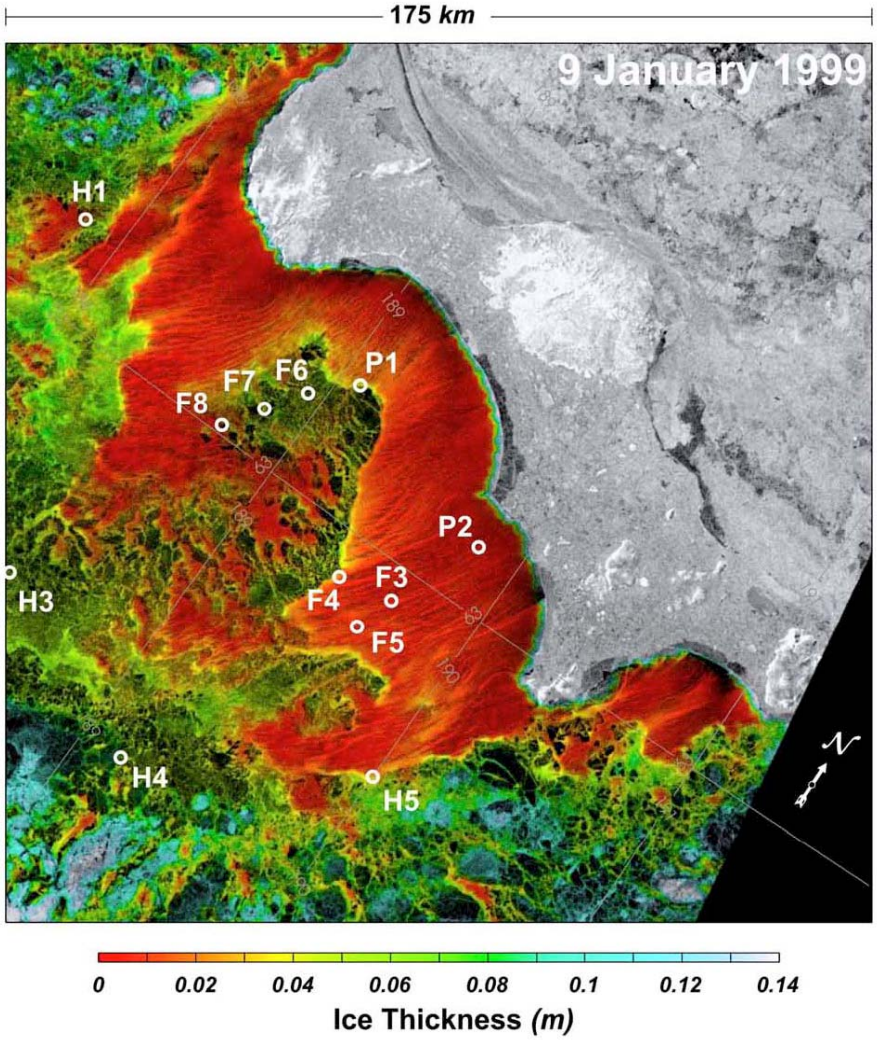

Figure 1: Composite SAR and AVHRR image of the St. Lawrence Island polynya on 9 January 1999, adapted from Drucker et al. [2003]. The polynya appears strongly wind-driven, with the winds and waves forcing the frazil ice into the long linear streaks characteristic of a Langmuir circulation. Mooring locations are plotted. SAR image copyright 1999 by the Canadian Space Agency.

IMPACT/APPLICATIONS

Our work on the northern Chukchi shelf is collaborative with K. Aagaard and R. Woodgate, UW; R. Pickart, WHOI, who is concentrating on the adjacent Beaufort shelf and slope; and with J. Swift, SIO, who has made hydrographic measurements throughout the SBI region. Additionally, we have ongoing collaborations in the region with E. Carmack and F. McLaughlin, IOS and S. Smith, L. Llinas, and D. Hansell of U. Miami.

Major goals of the SBI initiative are to understand the physical processes responsible for water mass modification over the arctic shelves and slopes, and for exchanges with the interior ocean, as well as to understand the variability of this system. Our reported project addresses these goals directly. In particular, we are quantifying the large variability found in the Pacific-origin waters that flush the western Arctic shelves, as well as illuminating the origin of this variability. Much of the latter is generated in the Bering Sea [*Woodgate et al.*, 2005a], although the northward-flowing waters may in some years be further modified in the Chukchi, particularly during winter along the Alaskan coast [*Weingartner et al.*, 2005]. The shelf waters are subsequently discharged into the Arctic Ocean, where their seasonal and interannual variability are propagated long distances, in part by long-lived eddies that drift into the interior [*Newton et al.*, 1974; *Manley and Hunkins*, 1985], in part by topographically steered boundary currents that rim both the Polar Basin and its major ridge structures [*Aagaard*, 1989], and in part by other features of the circulation. This propagation leads to variability in regions far from the originating shelves [cf., *Swift et al.*, 1997 and *Woodgate et al.*, 2001 for examples]. An understanding of these effects and processes is vital to realistically modeling the Arctic Ocean and its global connections [*Huang and Schmitt*, 1993; *Wadley and Bigg*, 2002; *DeBoer and Nof*, 2004]].

Our measurements of the time-dependent shelf circulation provide important guidance to investigations of shelf productivity and biochemical cycling. For example, water parcels leaving the northern Chukchi shelf will exhibit substantially different carbon and nutrient loading, depending on their upstream trajectories and the season [*Walsh et al.*, 1997; *Woodgate et al.*, 2005a]. Our work also addresses other prominent issues, including the role of polynyas [*Danielson et al.*, in press]; the flux and processing of freshwater [*Woodgate and Aagaard*, 2005; *Peterson et al.*, 2006; *Woodgate et al.*, 2006; *Aagaard et al.*, in press; *Serreze et al.*, in press]; mixing over the slope [*Woodgate et al.*, 2005b]; and the needs of a variety of arctic simulations for accurate long-term boundary conditions and observations for verification.

IMPACT/APPLICATIONS

Our work is providing the observations and interpretations required to understand how Pacific waters influence the structure and dynamics of the Arctic Ocean. In addition we are providing other SBI investigators with ancillary information necessary for interpreting biological and geochemical data collected during the SBI program. Our measurements will also provide data sets essential for evaluating and testing the numerical model activities being undertaken in SBI.

TRANSITIONS

All SBI investigators will use our data and interpretations in examining their data sets.

RELATED PROJECTS

Our SBI project complements moored observations and CTD sampling being collected in this region by other NSF-supported SBI participants as well as Japanese efforts led by K. Shimada (JAMSTEC) and Canadian sampling led by E. Carmack (Institute of Ocean Sciences).

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